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DRILLING AND TESTING GEOTHERMAL WELLS IN AN ACTIVE VOLCANIC DOMAIN, PUNA GEOTHERMAL FIELD, HAWAII, USA

W.L. D'Olier, Vice President
J.L. Iovenitti, Senior Geologist

Thermal Power Company[1]
San Francisco, California, USA

ABSTRACT

Thermal Power Company, Operator for the Puna Geothermal Venture which includes AMFAC and Dillingham, has drilled and tested two geothermal wells in the Puna Geothermal Field, Hawaii, USA. The field is located in the East Rift Zone of Kilauea which is one of the world's most active volcanoes. The wells were drilled to a depth of 7,290 and 8,005 feet and completed with 9 5/8" production casing to 4,200 feet and 7" perforated liner extending to bottom.

A high temperature, 660^{o}F plus, two-phase geothermal reservoir was encountered. Noncondensible gas concentration is only 0.2% by weight but contains 1,100 ppm H_2S which must be abated to meet environmental concerns. Flow testing proved to be a complex affair. However, 100% steam production has been identified in both wells with the assistance of a separator.

These two wells, along with the U.S. Department of Energy/University of Hawaii HGP-A well which now generates 3 MW of electric power, have defined a 25 MW reserve capacity on the Puna Geothermal Venture leasehold. A third well with substantially improved casing design will be drilled by Thermal later in 1984 to refine plans for the wellfield and generating plant.

INTRODUCTION

Volcanic activity is so prevalent throughout the Pacific Ocean Basin and Southeast Asia that many nations are embarked in the development of electric power from volcanic heat sources. The island of Hawaii, which is the largest composite volcanic structure on Earth, is also revealing its potential for an indigenous geothermal electric power base. The results may eventually ease the Hawaiian people's exposure to economic upset in the petroleum importation which now supports the greater portion of their electrical generation capacity.

The Puna Geothermal Venture (PGV) consists of three American business firms; Thermal Power Company, Dillingham Geothermal, Inc., and Amfac Energy, Inc. The objective of PGV is the development of geothermal energy for reliable electric

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1. Thermal Power Company is a wholly owned subsidiary of Diamond Shamrock Corporation. Thermal is an equal partner in a Geysers, California joint venture which owns approximately 175 geothermal steam wells producing to 984 megawatts of electrical generating capacity.

power production at a marketable price in Hawaii. Thermal, as Operator for PGV, recently completed the drilling and testing of two geothermal wells within the East Rift Zone of the active volcano Kilauea on the island of Hawaii (see Figure 1). The linear rift zone overlies the deep conduits which convey recurring magma transfers from the throat of Kilauea to the submarine aprons of this young volcanic edifice, east of Cape Kumakahi.

The potential of the rift is best indicated by the unique joint achievement of the State of Hawaii, the University of Hawaii and the U.S. Department of Energy acting together as the Hawaii Geothermal Project. Following the 1976 completion of a single, 6450-foot exploratory well (the HGP-A well) to an approximate 100,000 pound per hour flowing mixture of steam and water, a 3-megawatt turbine generator has been on line with a 93% availability factor since May 1982. The PGV drilling and testing operations, herein reported, were conducted in 1981 and 1982. Other competitive parties are active in exploring the geothermal resource of the East Rift Zone.

PREPARATIONS BY PGV FOR DRILLING AND TESTING

A large collection of published technical information was available to Thermal in the Hawaii Geothermal Project (HGP) reports published by the University of Hawaii. A number of geophysical, geochemical and shallow well water surveys pointed to geothermal fluid leakage in the rift, particularly at a distinctive tranverse structural offset, just west of the initial eruption site (Puu Hunuaula) of the 1955 volcanic episode. Recent detailed geologic mapping of the East Rift Zone lava sequences, vents and fissures was available from the Hawaii Volcano Observatory of the U.S. Geological Survey to better interpret its structure, dynamic processes and volcanic history. Both the Hawaii Volcano Observatory and the Hawaii Institute of Geophysics contributed published gravity, seismic and resistivity data which allowed Thermal to refine concepts of the deep geothermal reservoir and heat source indicated by the successful HGP-A well. This well was sited in the transverse offset and one early published interpretation, supported by micro seismic data, had the geothermal reservoir localized on this feature.

Technical evaluations by Thermal indicated the medial axis of the rift zone, northeast of the transverse offset, to be prospective for stepout drilling. PGV obtained an 816-acre State lease, which adjoined the HGP 4-acre project site on its northeast perimeter (see Figure 2). A drillsite 1800 feet northeast of the HGP-A well was chosen for the first well of an intended two-well drilling and testing program. The HGP-A well history provided a distinct advantage in the preparation of the drilling program for the initial well, Kapoho State 1. However, we concluded that the optimal production zone was entirely below the depth of 4000 feet (1220 meters). Accordingly, we planned a 7500-foot (2286 m.) well with production casing cemented to 4000 feet. Thermal put under contract the adequate mobile rig of the Hawaii drilling firm which was previously employed to drill the HGP-A well. All tubulars, drilling mud, cement additives, technical services and wellhead equipment were obtained from California sources. Thermal Power Company staff provided the management, on site supervision, geologic and engineering inputs to the entire drilling operation.

KAPOHO STATE 1 WELL

By November 1981, the initial well had been drilled to a total depth of 7290 feet (2222 m.) where it became difficult to maintain drilling mud performance against increasing bottom hole temperatures. A 9 5/8" K-55 and N-80, 46 pound per foot, buttress coupled casing string had been cemented at 4072 feet (1241 m.) before drilling into the production interval. A perforated 7" liner of K-55 and N-80, 26 pound per foot, was placed in the 8 1/2" diameter wellbore from 3897 to 7216 feet (1188 to 2199 m.). The well was drilled and completed within 65 days, in close conformance with the technical plan. Flow test preparations, including construction of a twin cyclone separator, were promptly accomplished. In the initial flow event, wellhead transient conditions of 546°F and 1454 psig were encountered with the arrival of the geothermal effluent. A 10" butterfly control valve also failed after 40 minutes of full flow mode because of heavy entrainment of iron sulfide particulates from the reservoir. The brief, vigorous initial flow did not afford any meaningful measure of mass flow rate or gas-liquid ratios. The installed 600 series wellhead gates would not provide a proper safety margin for the unexpectedly high peaks in wellhead flowing temperatures and pressure. Upgraded equipment and procedures were obviously required before additional flow testing could proceed.

KAPOHO STATE 2 WELL AND FLOW TEST

Thermal started the second PGV stepout well promptly, without waiting to specify the geothermal effluent at the initial well. The second well, Kapoho State 2 (KS-2) was bottomed at a total depth of 8005 feet (2440 m.) by late March 1982. The penetrated rock and reservoir interval were very similar to Kapoho State 1 (KS-1) well, approximately 1800 feet away. A comparable 9 5/8" casing string was cemented at 4209 feet (1283 m.) before drilling into the producing interval with 8 3/4" bits and fresh water drilling fluid. At 7150 feet (2179 m.) depth, the water was replaced with an improved drilling mud which allowed cost effective penetration of very high temperature rock to total depth. A similar 7" perforated liner was placed between 3981 and 7891 feet (1213 and 2405 m.). Well KS-2 was drilled and completed in 56 days and the well head was equipped with two 900 series gates.

Wellhead noise levels approaching 120 decibels and H_2S concentrations of 1100 ppm were revealed in the initial flow test attempt at Well KS-1. Accordingly, a rock filled, pit muffler, 15 feet on each side and 15 feet deep, was constructed to reduce the effluent venting velocity and noise levels. An H_2S chemical abatement system was integrated into the 10" flow metering line, downstream of the orifice plates and upstream of the lip pressure tap. This muffler-abatement combination substantially reduced both noise and H_2S levels to within regulatory standards and permit conditions. A brief vertical stacking interval was utilized on the initial opening to full flow at Well KS-2, hopefully to avoid the erosional failure of any key surface control equipment as did occur at Well KS-1. In the wellhead transient conditions, observed at several openings to full flow modes, a maximum of 583°F and 1333 psig was recorded at Well KS-2.

As testing proceeded, with several interruptions due to mechanical problems, it became clear that Well KS-2 was producing less liquid and more steam with time. A steel vessel separator with a tangential entry and internal spiral vanes was installed to effect the separation and measurement of the steam and liquid phases. In spite of wellbore obstructions, including rock bridges, lost Kuster recorder and 5,200 feet of wireline, a modest, stable flow rate at Well KS-2 was identified and measured with a separator. It proved to be 100% steam flow at 33,000 pounds per hour at 173 psig wellhead flowing pressure.

KAPOHO STATE 1 FLOW TEST

Well KS-1, standing in the shut-in mode without bleed, had attained a final static maximum pressure of 1435 psig at the wellhead. Preparations for flow test required a rig to kill the well, upgrade the wellhead gates to 900 series, make certain shallow casing repairs and clean out rock debris bridges in the 7" perforated liner with 6" bits and water circulation. The substantial risk in the clean out attempt was recognized and the penalty was harsh. A 270-foot element of drill collars and tools got stuck below 4570 feet (1393 m.) and could not be jarred loose. In spite of this blockage in the upper part of the 7" perforated liner, the subsequent flow test on the steel vessel separator yielded 100% steam at 72,000 pounds per hour at 120 psig wellhead pressure. The enthalpy of the geothermal wellhead fluid was approximately 1185 Btus per pound mass. Total noncondensible gas content was approximately 0.2% by weight which included an H_2S concentration of approximately 1100 ppm.

SUMMARY

1. A high quality, 100% steam product has been demonstrated from two geothermal wells completed in the Puna Geothermal Field. A comparison is made of steam production of KS-1, HGP-A and average Geysers wells in the following Table 1. The 50% geothermal liquid production in the HGP-A well may derive from the open wellbore interval between 4000 feet and the 2900-foot depth of its solid 7" production casing. Alternatively, this well may be completed in the edge of the productive reservoir.

2. The three wells, KS-1 and 2 and HGP-A have established a geothermal resource reserve adequate for 25 megawatts of electrical generating capacity on a portion of the State of Hawaii lease owned by Puna Geothermal Venture. PGV responded in January 1984 to a Request for Proposal from the Hawaii Electric Lighting Company (HELCO) which is the electric utility company operating on the island of Hawaii.

3. The Puna geothermal reservoir is situated below 4000 feet and within the linear structure of the East Rift Zone. Reservoir rocks are a sequence of submarine basaltic lavas intruded by younger dikes. The porous and permeable zones between the lavas flows appear to be the productive zones. The geothermal fluids are indicated, by pressure-temperature survey, to reside on the boiling point curve within the reservoir. Reservoir temperatures increase with depth; Well KS-1 provided a maximum recordable wellbore temperature of 650°F at 6400 feet (1951 m.). The Well KS-2 maximum was 670°F at 6900 feet (2103 m.). Rock debris bridges and instrument limitations combined to preclude measurement of the presumed higher temperatures at greater wellbore depths.

4. Both wells are presently suspended securely with deep, drillable cement plugs. Additional drilling plans and wellfield, plant and environmental studies are

completing. The recent Kilauea volcanic activity has not extended to the lower East Rift Zone. However, clustered wellheads, to reduce surface piping, and elevated plant site are foreseen as basic steps to defend against the commonest volcanic event, lava flows up to 40 feet thick. The analysis of local seismic history indicates that California seismic standards for electrical generating plant will be entirely adequate on the island of Hawaii.

CONCLUSIONS

The feasibility for geothermal electric power system in the active, volcanic East Rift Zone of Kilauea, first demonstrated by the Hawaii Geothermal Project, has been significantly enhanced by the two Kapoho State wells demonstration of a 100% steam production.

Effective well flow testing is a difficult and most critical task in qualifying new geothermal reservoirs in volcanic domains. Careful planning in opening wells, attaining clean and stable fluid flows, and obtaining accurate identification and measurement of the produced fluids will require a major commitment of funds and superior equipment.

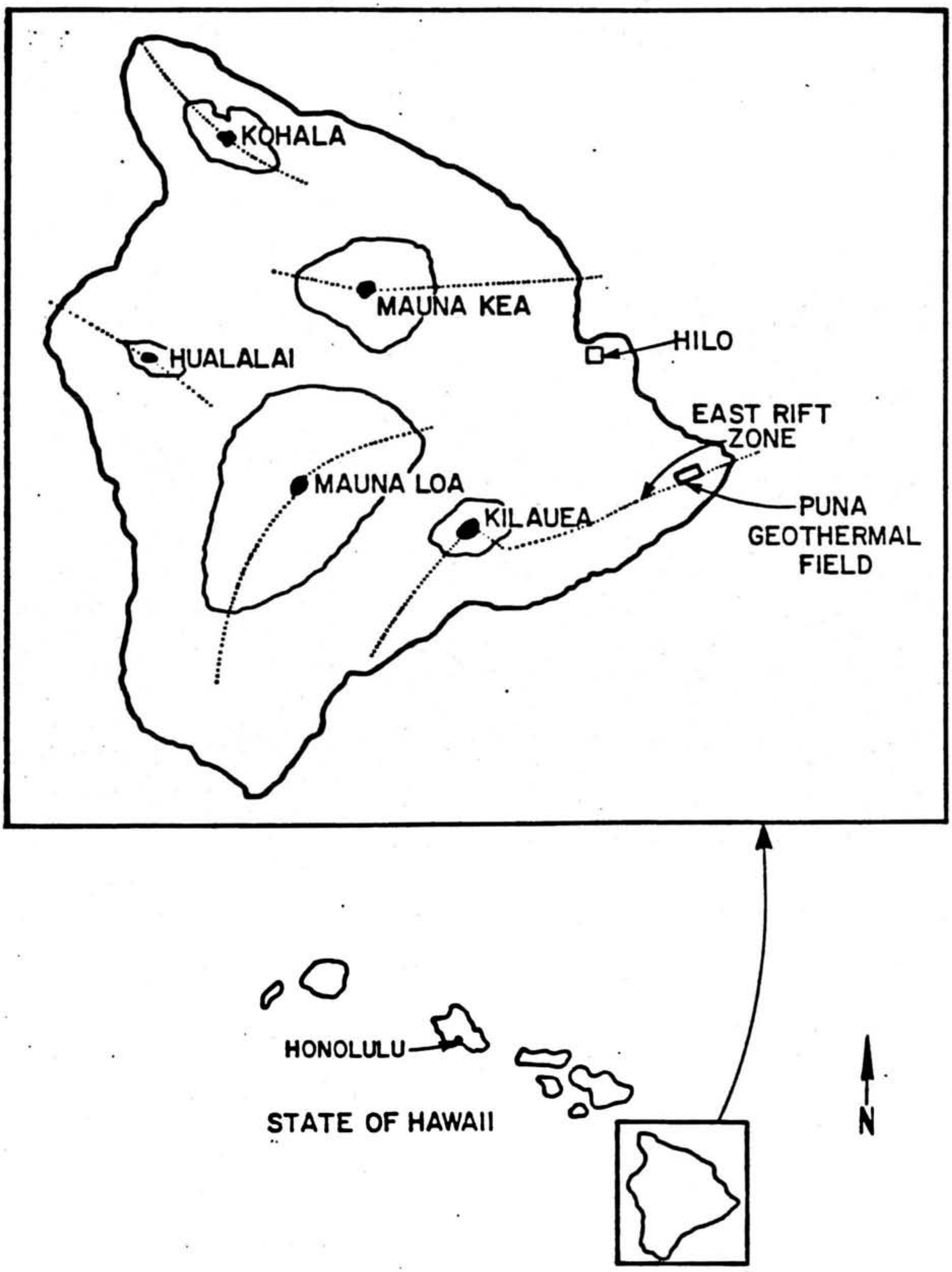
Technical challenges and higher development costs are indicated by the Kapoho State wells. Thermal carefully reviewed its Puna drilling, completion and testing experiences. A third well program, with upgraded casing, cementing and completion procedures has been prepared by Thermal and its engineering consultants to best fit the unique characteristics of the Puna Geothermal Field. The third well will be drilled later in 1984 to confirm effluent production parameters and performance in order to estimate wellfield development costs and initiate power plant design.

TABLE 1

	HGP-A	KS-1	GEYSERS
Steam Fraction	50%	100%	100%
Flow Rates lbs. per hr.	50,000	72,000	100,000 - 200,000
Reservoir Temperature	500 - 678°F	550 - 670°F	470°F
H_2S	900 ppm	1100 ppm	400 ppm
Wells	1	2	280
Production Span	2 years	----	24 years
Plant Capacity	3 MW	----	1279 MW

FIGURE I.

VOLCANOES AND RIFT ZONES
ISLAND OF HAWAII



PUNA GEOTHERMAL FIELD
ISLAND OF HAWAII

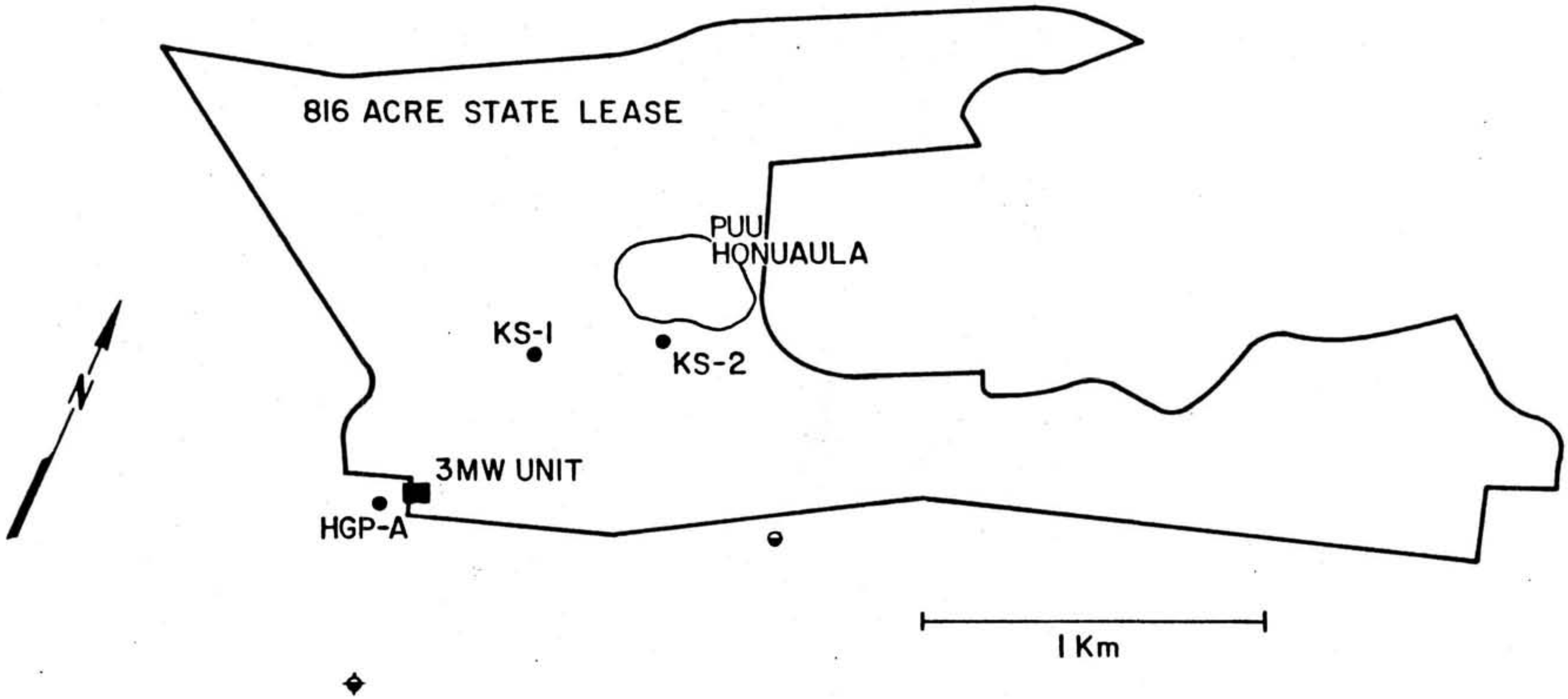


FIGURE 2